Employing **`asremlPlus`**, in conjunction with **`asreml`**, to calculate and use information criteria

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11 November, 2020

This vignette illustrates the facilities in **`asremlPlus`** (Brien, 2020), in conjunction with **`asreml`** (Butler et al., 2018), for calculating and using information. Here, **`asremlPlus`** and **`asreml`** are packages for the R Statistical Computing environment (R Core Team, 2020).

It is divided into the following main sections:

1. Set up the maximal model for this experiment
2. Obtaining information criteria for separate models
3. Obtaining information criteria for a prescribed sequence of model changes
4. Using information criteria to decide model changes

1. Set up the maximal model for this experiment

```
library(knitr)
opts_chunk$set("tidy" = FALSE, comment = NA)
suppressMessages(library(asreml, quietly=TRUE))
packageVersion("asreml")
```

```
## [1] '4.1.0.130'
```

```
suppressMessages(library(asremlPlus))
packageVersion("asremlPlus")
```

```
## [1] '4.2.25'
```

```
options(width = 100)
```

Get data available in asremlPlus

The data are from a 1976 spring wheat experiment and are taken from Gilmour et al. (1995). An analysis is presented in the **`asreml`** manual by Butler et al. (2018, Section 7.6), although they suggest that it is a barley experiment.

```
data(Wheat.dat)
```

Fit the maximal model

In the following a model is fitted that has the terms that would be included for a balanced lattice. In addition, a term WithinColPairs has been included to allow for extraneous variation arising between pairs of adjacent lanes. Also, separable ar1 residual autocorrelation has been included. This model represents the maximal anticipated model,

```
max.asr <- asreml(yield ~ WithinColPairs + Variety,
                  random = ~ Rep/(Row + Column) + units,
                  residual = ~ ar1(Row):ar1(Column),
                  data=Wheat.dat)
```

```
License check Wed Nov 11 10:56:25 2020
Model fitted using the gamma parameterization.
ASReml 4.1.0 Wed Nov 11 10:56:25 2020
          LogLik        Sigma2    DF      wall    cpu
1       -724.121      23034.14   124 10:56:25    0.0
2       -717.415       9206.93   124 10:56:25    0.0 (2 restrained)
3       -694.875      26492.99   124 10:56:25    0.0 (2 restrained)
4       -694.160      33101.80   124 10:56:25    0.0 (1 restrained)
5       -692.002      36912.26   124 10:56:25    0.0 (1 restrained)
6       -691.789      46701.51   124 10:56:25    0.0 (2 restrained)
7       -691.834      46208.51   124 10:56:25    0.0 (1 restrained)
8       -691.775      47698.26   124 10:56:25    0.0
9       -691.771      47041.85   124 10:56:25    0.0
```

```
Warning in asreml(yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Some components changed
by more than 1% on the last iteration.
```

The warning from `asreml` is probably due to a bound term.

Initialize a testing sequence by loading the current fit into an asrtests object

```
max.asrt <- as.asrtests(max.asr, NULL, NULL)
```

```
Calculating denominator DF
```

Check for and remove any boundary terms

```
max.asrt <- rmboundary(max.asrt)
summary(max.asrt$asreml.obj)$varcomp
```

```
                          component      std.error     z.ratio bound  %ch
Rep:Row               4.293282e+03 3.199458e+03  1.3418779     P  0.0
Rep:Column            1.575689e+02 1.480357e+03  0.1064398     P  0.7
units                 5.742689e+03 1.652457e+03  3.4752438     P  0.0
Row:Column!R          4.706787e+04 2.515832e+04  1.8708669     P  0.0
Row:Column!Row!cor    7.920301e-01 1.014691e-01  7.8056280     U  0.0
Row:Column!Column!cor 8.799559e-01 7.370402e-02 11.9390486     U  0.0
```

```
print(max.asrt, which = "testsummary")
```

```
####   Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

   terms DF denDF  p AIC BIC   action
1    Rep  1    NA NA  NA  NA Boundary
```

Rep has been removed because it has been constrained to zero. Following the recommendation of Littel et al. (2006, p. 150), the bound on all variance components is set to unconstrained (U) using

`setvariances.asreml` so as to avoid bias in the estimate of the residual variance. Alternatively, one could move Rep to the fixed model.

Unbind Rep, Row and Column components and reload into an asrtests object

```
max.asr <- setvarianceterms(max.asr$call,
                            terms = c("Rep", "Rep:Row", "Rep:Column"),
                            bounds = "U")
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Wed Nov 11 10:56:26 2020
          LogLik        Sigma2     DF     wall     cpu
   1     -724.121     23034.14    124 10:56:26   0.0
   2     -717.415      9206.93    124 10:56:26   0.0 (2 restrained)
   3     -694.875     26492.99    124 10:56:26   0.0 (2 restrained)
   4     -693.974     33129.65    124 10:56:26   0.0 (1 restrained)
   5     -692.886     39662.12    124 10:56:26   0.0
   6     -691.428     53103.83    124 10:56:26   0.0
   7     -691.239     48092.17    124 10:56:26   0.0
   8     -691.181     47278.94    124 10:56:26   0.0
   9     -691.171     46850.98    124 10:56:26   0.0
  10     -691.170     46690.46    124 10:56:26   0.0
```

```
Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Some components
changed by more than 1% on the last iteration.
```

```
max.asrt <- as.asrtests(max.asr, NULL, NULL)
```

```
Calculating denominator DF
```

```
max.asrt <- rmboundary(max.asrt)
summary(max.asrt$asreml.obj)$varcomp
```

```
                        component     std.error    z.ratio bound %ch
Rep                 -2462.3785855 1.191435e+03  -2.066734     U 0.2
Rep:Row              5012.4021413 3.396848e+03   1.475604     U 0.1
Rep:Column            920.5936388 1.704008e+03   0.540252     U 1.1
units                5964.9099374 1.608792e+03   3.707695     P 0.1
Row:Column!R        46690.4620355 2.731906e+04   1.709080     P 0.0
Row:Column!Row!cor      0.8152180 9.988929e-02   8.161216     U 0.1
Row:Column!Column!cor   0.8857252 7.487875e-02  11.828793     U 0.0
```

```
print(max.asrt, which = "testsummary")
```


```
####  Sequence of model investigations
```

```
(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)
```

```
[1] terms  DF    denDF  p      AIC    BIC    action
<0 rows> (or 0-length row.names)
```

Now the Rep component estimate is negative.

The `test.summary` output shows that no changes have been made to the model loaded using `as.asrtests`. The pseudo-anova table shows that Varieties are highly significant ($p < 0.001$)

2. Obtaining information criteria for separate models

The method `infoCriteria` has two methods for calculating information criteria. One, `infoCriteria.asreml`, is a method for `asreml` objects and the other, `infoCriteria.list`, if for 'listobjects, the components of thelistbeingasreml' objects.

Single models

Firstly, `infoCriteria` is called with the default `IClikelihood`, which is `REML`. Then it is called with `IClikelihood` set to `full` (Verbyla, 2019).

```
infoCriteria(max.asr)
```

```
  fixedDF varDF NBound    AIC     BIC  loglik
1       0     7      0 1396.34 1416.082 -691.17
```

```
infoCriteria(max.asr, IClikelihood = "full")
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Wed Nov 11 10:56:26 2020
         LogLik      Sigma2   DF    wall    cpu
 1      -691.170   46641.98   124 10:56:26   0.0
```

```
Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood
not converged
```

```
  fixedDF varDF NBound    AIC      BIC    loglik
1      26     7      0 1647.193 1746.544 -790.5967
```

A list of models

Now, a second model, from which the `withinColPairs` term has been omitted, is fitted; to be consistent, the variance components are unconstrained using `setvariances.asreml`. Then the `asreml` objects for this model and the maximal model are combined into a `list` and a `data.frame` produced that includes their information criteria.

```
m1.asr <- asreml(yield ~ Variety,
                 random = ~ Rep/(Row + Column) + units,
                 residual = ~ ar1(Row):ar1(Column),
                 data=Wheat.dat)
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Wed Nov 11 10:56:26 2020
         LogLik      Sigma2   DF    wall    cpu
 1      -727.774   22898.99   125 10:56:26   0.0
 2      -721.097    9190.30   125 10:56:26   0.0 (2 restrained)
 3      -698.313   26671.76   125 10:56:26   0.0 (2 restrained)
 4      -697.517   32677.28   125 10:56:26   0.0 (1 restrained)
 5      -695.419   36662.27   125 10:56:26   0.0 (1 restrained)
 6      -695.208   46263.96   125 10:56:26   0.0 (2 restrained)
 7      -695.198   46156.63   125 10:56:26   0.0
 8      -695.191   46630.21   125 10:56:26   0.0
```

```
Warning in asreml(yield ~ Variety, random = ~Rep/(Row + Column) + units, : Some components changed
by more than 1% on the last iteration.
```

```
m1.asr <- setvarianceterms(m1.asr$call,
                           terms = c("Rep", "Rep:Row", "Rep:Column"),
                           bounds = "U")
```

```
Model fitted using the gamma parameterization.
ASReml 4.1.0 Wed Nov 11 10:56:26 2020
          LogLik        Sigma2      DF       wall      cpu
 1       -727.774      22898.99     125 10:56:27    0.0
 2       -721.097       9190.30     125 10:56:27    0.0 (2 restrained)
 3       -698.313      26671.76     125 10:56:27    0.0 (2 restrained)
 4       -697.333      32689.33     125 10:56:27    0.0 (1 restrained)
 5       -697.016      39975.97     125 10:56:27    0.0
 6       -695.070      54825.30     125 10:56:27    0.0
 7       -694.757      47637.20     125 10:56:27    0.0
 8       -694.644      46775.41     125 10:56:27    0.0
 9       -694.618      46175.06     125 10:56:27    0.0
10       -694.615      45940.69     125 10:56:27    0.0
```

Warning in asreml(fixed = yield ~ Variety, random = ~Rep/(Row + Column) + : Some components changed
by more than 1% on the last iteration.

```r
mods <- list(max = max.asr, m1 = m1.asr)
ic <- infoCriteria(mods, IClikelihood = "full")
print(ic)
```

```
    fixedDF varDF NBound      AIC      BIC    loglik
max      26     7      0 1647.193 1746.544 -790.5967
m1       25     7      0 1645.326 1741.666 -790.6629
```

3. Obtaining information criteria for a prescribed sequence of model changes

The use of `changeTerms.asrtests` is demonstrated for a sequence of models, starting with the maximal model.

Drop the term for within Column pairs (a post hoc factor)

```r
current.asrt <- as.asrtests(max.asrt$asreml.obj, NULL, NULL,
                            label = "Maximal model", IClikelihood = "full")
```

Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood
not converged

Calculating denominator DF

```r
current.asrt <- changeTerms(current.asrt, dropFixed = "WithinColPairs",
                            label = "Drop withinColPairs", IClikelihood = "full")
```

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.

Calculating denominator DF
Calculating denominator DF

```r
print(current.asrt, which = "testsummary", omit.columns = "p")
```

```
#### Sequence of model investigations
```

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

```
            terms DF denDF      AIC      BIC        action
1      Maximal model 26     7 1647.193 1746.544 Starting model
2 Drop withinColPairs 25     7 1645.326 1741.666  Changed fixed
```

So the same values of the information criteria have been obtained as when `infoCriteria.list` was used on a `list` containing the `asreml` objects for the two models. The differences is that here there is ultimately only one fitted model, the model stored in the `asreml` object in the `asrtests` object named `current.asrt`: this is the model with `withinColPairs` omitted.

Note this use of the `omit.columns` argument from `print.test.summary` to omit the irrelevant column p from the `test.summary`.

Drop nugget term

```
current.asrt <- changeTerms(current.asrt, dropRandom = "units",
                            label = "Drop units", IClikelihood = "full")
```

```
Warning in asreml(fixed = yield ~ Variety, random = ~Rep + Rep:Row + Rep:Column, : Some components
changed by more than 1% on the last iteration.
```

```
Calculating denominator DF
Calculating denominator DF
```

Check Row autocorrelation

```
current.asrt <- changeTerms(current.asrt, newResidual = "Row:ar1(Column)",
                            label="Row autocorrelation", IClikelihood = "full")
```

```
Calculating denominator DF
Calculating denominator DF
```

```
print(current.asrt, which = "testsummary", omit.columns = "p")
```

```
####   Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

             terms DF denDF      AIC      BIC         action
1      Maximal model 26     7 1647.193 1746.544   Starting model
2 Drop withinColPairs 25     7 1645.326 1741.666    Changed fixed
3          Drop units 25     6 1650.126 1743.456    Changed random
4 Row autocorrelation 25     5 1660.882 1751.201 Changed residual
```

4. Using information criteria to decide model changes

This sections illustrates the use of `changeModelOnIC.asrtests` to decide between consecutive models in a sequence of models. The default information criterion to use for this is the `AIC`. However, `which.IC` can be used to specify the use of the `BIC` or `both`. Here we use the `AIC` and the `full` likelihood.

Check the term for within Column pairs (a post hoc factor)

As before, we start with the maximal model, in which the variance components have been unconstrained and look to decide whether of not to drop the `withinColPairs` term.

```
current.asrt <- as.asrtests(max.asrt$asreml.obj, NULL, NULL,
                            label = "Maximal model", IClikelihood = "full")
```

Warning in asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood
not converged

Calculating denominator DF

```
current.asrt <- iterate(current.asrt)
```

Calculating denominator DF

```
current.asrt <- changeModelOnIC(current.asrt, dropFixed = "WithinColPairs",
                                label = "withinColPairs",
                                IClikelihood = "full", which.IC = "AIC",
                                allow.unconverged = FALSE)
```

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components
changed by more than 1% on the last iteration.

Calculating denominator DF
Calculating denominator DF

```
print(current.asrt, which = "testsummary", omit.columns = "p")
```


Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

```
            terms DF denDF        AIC        BIC       action
1   Maximal model 26     7 1647.193455 1746.544420 Starting model
2 withinColPairs -1     0   -1.867556   -4.878191        Swapped
```

Given the warning about a lack of convergence, we use `iterate.asrtests` to perform additional iterations of the fitting process. It seems that it was successful.

It can be seen from the `test.summary` that the term has been swapped out and this has the effect of reducing the number of fixed parameters by one and makes no change to the variance parameters.

Check the nugget term

```
current.asrt <- changeModelOnIC(current.asrt, dropRandom = "units",
                                label = "units", IClikelihood = "full",
                                allow.unconverged = FALSE)
```

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + Rep:Row + Rep:Column, : Some components
changed by more than 1% on the last iteration.

Calculating denominator DF
Calculating denominator DF

Check Row autocorrelation

```
current.asrt <- changeModelOnIC(current.asrt, newResidual = "Row:ar1(Column)",
                                label="Row autocorrelation", IClikelihood = "full",
                                allow.unconverged = FALSE)
```

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Log-likelihood not converged

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components changed by more than 1% on the last iteration.

Warning in newfit.asreml(asreml.obj, fixed. = fix.form, random. = ran.form, :

Calculating denominator DF

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components changed by more than 1% on the last iteration.

Calculating denominator DF

Warning in asreml(fixed = yield ~ Variety, random = ~Rep + units + Rep:Row + : Some components changed by more than 1% on the last iteration.

Check Column autocorrelation (depends on whether Row autocorrelation retained)

```
{
  last.action <- current.asrt$test.summary$action[current.asrt$test.summary$terms ==
                                                    "Row autocorrelation"]
  if (grepl("Unswapped", last.action, fixed = TRUE) |
      grepl("Unchanged", last.action, fixed = TRUE))
    current.asrt <- changeModelOnIC(current.asrt, newResidual = "ar1(Row):Column",
                                     label="Col autocorrelation", IClikelihood = "full",
                                     allow.unconverged = FALSE)
  else
    current.asrt <- testresidual(current.asrt, newResidual = "Row:Column",
                                  label="Col autocorrelation", IClikelihood = "full",
                                  allow.unconverged = FALSE)
}
```

Calculating denominator DF

Warning in infoCriteria.asreml(asreml.obj, IClikelihood = ic.lik, bound.exclusions = bound.exclusions):
 Row:Column!Row!cor

Calculating denominator DF

Warning in infoCriteria.asreml(new.asrtests.obj$asreml.obj, IClikelihood = ic.lik, : The following bound
 Row:Column!Row!cor

Output the results

```
print(current.asrt, which = "test", omit.columns = "p")
```

```
#### Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

              terms DF denDF        AIC         BIC                   action
1     Maximal model 26     7 1647.193455 1746.544420          Starting model
2     withinColPairs -1     0   -1.867556   -4.878191                 Swapped
```

```
3                    units  0   -1   4.801145   1.790510                   Unswapped
4 Row autocorrelation  0   -1  17.819174  14.808538 Unchanged - new unconverged
5 Col autocorrelation  0   -2  19.479776  13.458506                   Unswapped
```

```
summary(current.asrt$asreml.obj)$varcomp
```

```
                        component     std.error    z.ratio bound %ch
Rep                  -2391.9489939 1.194581e+03 -2.0023338     U 0.4
Rep:Row               5035.5311054 3.406006e+03  1.4784269     U 0.3
Rep:Column             761.9535622 1.612103e+03  0.4726458     U 1.2
units                 5933.2133794 1.610805e+03  3.6833848     P 0.1
Row:Column!R         45970.8383027 2.635124e+04  1.7445415     P 0.0
Row:Column!Row!cor       0.8101615 9.995498e-02  8.1052641     U 0.1
Row:Column!Column!cor    0.8846970 7.503039e-02 11.7911827     U 0.0
```

The `test.summary` shows us that the model without the autocorrelation failed to converge and so no change was made to the model. It, and the messages from checking the Column autocorrelation, also show us that the omission of the Column autocorrelation resulted in the Row autocorrelation becoming bound. That is, dropping the Column autocorrelation resulted in the dropping of two variance parameters

The function `printFormulae.asreml` is used to display the fitted model.

```
printFormulae(current.asrt$asreml.obj)
```

```
#### Formulae from asreml object

fixed: yield ~ Variety
random: ~ Rep + units + Rep:Row + Rep:Column
residual: ~ ar1(Row):ar1(Column)
```

References

Brien, C. J. (2020) `asremlPlus`: *Augments ASReml-R in fitting mixed models and packages generally in exploring prediction differences.* Version 4.2-15. http://cran.r-project.org/package=asremlPlus/ or http://chris.brien.name/rpackages/.

Butler, D. G., Cullis, B. R., Gilmour, A. R., Gogel, B. J. and Thompson, R. (2018). *ASReml-R Reference Manual Version 4.* VSN International Ltd, http://asreml.org.

Gilmour, A. R., Thompson, R., & Cullis, B. R. (1995). Average Information REML: An Efficient Algorithm for Variance Parameter Estimation in Linear Mixed Models. *Biometrics*, **51**, 1440–1450.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O. (2006). *SAS for Mixed Models* (2nd ed.). Cary, N.C.: SAS Press.

R Core Team (2020) `R`: *A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. http://www.r-project.org.

Verbyla, A. P. (2019). A note on model selection using information criteria for general linear models estimated using REML. *Australian & New Zealand Journal of Statistics*, **61**, 39-50. https://doi.org/10.1111/anzs.12254.